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EFFECTS OF TRAILING-EDGE MODIFICATIONS ON PITCHING-MOMENT CHARACTERISTICS OF AIRFOILS

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SUMMARY

The available data on the effects of trailing-edge modifications on the pitching-moment characteristics of airfoils have been collected and briefly analyzed. With the control-surface gap sealed, the location of the airfoil aerodynamic center moved forward as the included angle between the upper and lower surfaces of the airfoil at the trailing edge was increased and as the airfoil thickness at 0.9 chord was increased. The variation of pitching-moment coefficient with control-surface deflection, at constant lift coefficient with gap sealed, decreased as the trailing-edge angle was increased but the effects of the airfoil thickness near the trailing edge could not be determined because of insufficient data.

The addition of roughness to the airfoil leading edge appeared to intensify the tendency of trailing-edge modifications to move the aerodynamic center. Changes in Reynolds number within the test range did not appear to change the effects of trailing-edge modifications on the pitching-moment characteristics. No attempt was made to determine the effects of unsealed control-surface gaps on the pitching-moment characteristics because of the scarcity and inconsistency of the data.

INTRODUCTION

Recent unpublished tests of a complete model in the LMAL 7- by 10-foot tunnel showed that the location of the wing aerodynamic center was approximately 5 percent of the wing chord ahead of the location computed from large-scale tests of the airfoil sections. When an attempt was made to find the cause of the discrepancy, it was noted that the trailing edge of the wing had been modified from the basic cusped contour to a slightly bulged contour and that no account had been taken of this change in computing the aerodynamic-center location for the model wing. Some of the available data indicated that about one half of the difference in aerodynamic-center location could be attributed to this trailing-edge modification.

Previous investigations and analyses of data on trailing-edge modifications (references 1 to 6) have been concerned primarily with hinge-moment characteristics of control surfaces. The present paper is an attempt to extend the previous work to include the airfoil pitching-moment characteristics. It was thought advisable to include at the same time an analysis of the effect of trailing-edge modifications on the variation of pitching-moment coefficient with control-surface deflection for possible application to wing-twist problems in lateral control at high speeds.

SYMBOLS

c_l section lift coefficient

c_m section pitching-moment coefficient about airfoil quarter-chord point

α angle of attack, degrees

δ control-surface deflection relative to airfoil chord line, degrees

c airfoil chord

c_f control-surface chord back of hinge line

ϕ trailing-edge angle; that is, included angle between upper and lower surfaces at trailing edge of airfoil or control surface, degrees

$t_{0.9c}$ thickness of the airfoil section at 0.9 chord

$\frac{pb}{2V}$ wing-tip helix angle, radians

p	rate of roll
b	wing span
R_e	effective Reynolds number $\left(\frac{\rho Vc}{\mu} \times \text{Turbulence factor}\right)$
q	dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$
V	velocity of airstream
ρ	mass density of air
μ	coefficient of viscosity of air

$$\left.\begin{aligned} c_{m_{c_l}} &= \left(\frac{\partial c_m}{\partial c_l}\right)_\delta \\ c_{m_\delta} &= \left(\frac{\partial c_m}{\partial \delta}\right)_{c_l} \end{aligned}\right\}$$ where subscripts outside parentheses indicate factors held constant during measurement of parameters

$\Delta\phi$	increment of trailing-edge angle, where angle of true-contour surface is used as base
$\Delta t_{0.9c}$	increment of airfoil thickness at 0.9 chord, where true-contour surface is used as base

$$\left.\begin{aligned} &\Delta c_{m_{c_l}} \\ &\Delta c_{m_\delta} \end{aligned}\right\}$$ increments of slopes of pitching-moment curves, where data for true-contour surface is used as base

AVAILABLE DATA

All the data used in the present analysis consist of measurements of section characteristics (infinite aspect ratio) and were obtained from references 1 to 5 and unpublished data from Langley Memorial Aeronautical Laboratory and Ames Aeronautical Laboratory. The principal geometric characteristics and test conditions for the various models are given in table I. The slopes of the pitching-moment curves were measured at an angle of attack of 0° and with the control surface neutral. The slopes are applicable over ranges of α and δ of approximately ±5° and ±10°, respectively.

DISCUSSION

Previous analysis of the effect of trailing-edge modification on control-surface hinge moments (reference 6) indicated that the trailing-edge angle was a convenient basis for correlation of the data. The present analysis, although made on the same basis, indicated that when the trailing-edge angle was used as a parameter a consistent variation in the location of the airfoil aerodynamic center with changes in airfoil thickness near the trailing edge still occurred; accordingly, the thickness at the 0.9-chord station was arbitrarily chosen as an additional parameter.

Location of the airfoil aerodynamic center.- The effect of trailing-edge modifications on the location of the aerodynamic center with reference to the quarter-chord point and expressed in terms of the slope of the pitching-moment curve $\left(\partial c_m/\partial c_l\right)_\delta$ is shown in figure 1, which was derived from cross plots of the data of references 1 to 5 and of unpublished data. The values in this figure are presented as increments based on the characteristics of the normal airfoil profile. As the included angle between the upper and lower surfaces of the airfoil at the trailing edge is increased, and as the thickness at 0.9c is increased, the aerodynamic center moves forward.

A comparison of the measured values of $\Delta c_{m_{c_l}}$ with the computed values determined from figure 1 is presented in figure 2. Fixing transition near the airfoil leading edge (three symbols with downward flags) appears to intensify the tendency of the trailing-edge modifications to move the aerodynamic center. Figure 2 also indicates that changes in Reynolds number (symbols with upward flags) do not appear to affect the aerodynamic-center location, since only one of the points which indicate a high Reynolds number is an appreciable distance from the line of agreement and that one point is accompanied by a point which indicates a low Reynolds number for the same airfoil.

For a complete airplane model recently tested in the LMAL 7- by 10-foot tunnel (unpublished data), the wing-trailing-edge angle was increased by about 15° and the thickness at 0.9c was increased about 0.012c when the airfoil was modified from the basic cusped contour to a slightly bulged contour. This change in trailing edge would move the aerodynamic center of the wing forward by about $2\frac{1}{2}$ percent of the wing chord, which for this model would result in a tail load of about twice the estimated tail load in a pull-out from a dive. The magnitude of this increase in tail load was, of course, a function of the particular model characteristics and would not be expected to apply to other airplane models.

Variation of pitching-moment coefficient with control-surface deflection.- The effect of trailing-edge modifications on the variation of pitching-moment coefficient with control-surface deflection at constant lift is shown in figure 3 for control-surface chords of 20, 30, and 40 percent of the airfoil chord. Increasing the trailing-edge angle reduced the negative value of the slope of the curve of pitching-moment coefficient plotted against control-surface deflection at constant lift coefficient c_{m_δ}. Some additional effects of Reynolds number and airfoil thickness undoubtedly exist but the data were not sufficient to allow an evaluation of these effects.

A comparison of the data from figure 3 with that from figure 1(a) of reference 8 indicates that a change of 10° in the trailing-edge angle will change the value of c_{m_δ} by 20 to 30 percent of the value for a plain NACA 0009 airfoil section. Inasmuch as the loss of lateral control for constant aileron deflection at high speeds is primarily caused by wing twist, which in turn is approximately proportional to the value of c_{m_δ} at constant lift, changes in the trailing-edge angle can be seen to have an appreciable effect on the lateral control available at high speeds.

As a check on the preceding analysis, flight-test measurements of the rolling effectiveness of cusped and of beveled ailerons were compared to determine the effect of the bevel on the rate at which wing twist reduced the effectiveness at high speeds. The effectiveness data were taken from reference 9 and from unpublished flight data for the same airplane and are presented in figure 4 as curves of $\partial\frac{pb}{2V}/\partial\delta$ plotted against dynamic pressure. The value of c_{m_δ} for the cusped aileron was estimated from unpublished data, and the increment due to the bevel was obtained from figure 3(a). At indicated airspeeds above 300 miles per hour, the measured rate of loss of aileron effectiveness with speed $\frac{\partial\left(\partial\frac{pb}{2V}/\partial\delta\right)}{\partial q}$ for the beveled aileron was 71 percent of that for the cusped aileron, and the rate of loss of effectiveness for the beveled aileron obtained by using only the ratio of the estimated c_{m_δ} values for the two ailerons and neglecting Mach number effects was 64 percent of that for the cusped aileron.

CONCLUSIONS

Analysis of available data on the effects of trailing-edge modifications on the pitching-moment characteristics of airfoils indicates the following conclusions:

1. The airfoil aerodynamic center moves forward as the trailing-edge angle is increased and as the airfoil thickness at 0.9 chord is increased.

2. The variation of pitching-moment coefficient with control-surface deflection at constant lift coefficient decreases as the trailing-edge angle is increased.

3. Fixing transition near the airfoil leading edge appeared to intensify the tendency of trailing-edge modifications to move the aerodynamic center.

4. Changes in Reynolds number do not appear to change the effects of trailing-edge modifications on the

pitching-moment characteristics when the trailing-edge angle and thickness near the airfoil trailing edge are used as parameters.

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REFERENCES

1. Jones, Robert T., and Ames, Milton B., Jr.: Wind-Tunnel Investigation of Control-Surface Characteristics. V - The Use of a Beveled Trailing Edge to Reduce the Hinge Moment of a Control Surface. NACA ARR, March 1942.

2. Lockwood, Vernard E.: Wind-Tunnel Investigation of Control-Surface Characteristics. XVII - Beveled-Trailing-Edge Flaps of 0.20, 0.30, and 0.40 Airfoil Chord on an NACA 0009 Airfoil. NACA ACR No. L4D12, 1944.

3. Purser, Paul E., and Riebe, John M.: Wind-Tunnel Investigation of Control-Surface Characteristics. XV - Various Contour Modifications of a 0.30-Airfoil-Chord Plain Flap on an NACA 66(215)-014 Airfoil. NACA ACR No. 3L20, 1943.

4. Crane, Robert M., and Holtzclaw, Ralph W.: Wind-Tunnel Investigation of Ailerons on a Low-Drag Airfoil. I - The Effect of Aileron Profile. NACA ACR No. 4A14, 1944.

5. Crane, Robert M., and Holtzclaw, Ralph W.: Wind-Tunnel Investigation of Ailerons on a Low-Drag Airfoil. II - The Effect of Thickened and Beveled Trailing Edges. NACA ACR No. 4A15, 1944.

6. Purser, Paul E., and Gillis, Clarence L.: Preliminary Correlation of the Effects of Beveled Trailing Edges on the Hinge-Moment Characteristics of Control Surfaces. NACA CB No. 3E14, 1943.

7. Jacobs, Eastman N., Abbott, Ira H., and Davidson, Milton: Supplement (loose-leaf) to NACA Advance Confidential Report, Preliminary Low-Drag-Airfoil and Flap Data from Tests at Large Reynolds Numbers and Low Turbulence. NACA, March 1942.

8. Ames, Milton B., Jr., and Sears, Richard I.: Determination of Control-Surface Characteristics from NACA Plain-Flap and Tab Data. NACA Rep. No. 721, 1941.

9. Rogallo, F. M.: Collection of Balanced-Aileron Test Data. NACA ACR No. 4A11, 1944.

TABLE I

PRINCIPAL GEOMETRIC CHARACTERISTICS AND TEST CONDITIONS FOR MODELS CONSIDERED IN THE ANALYSIS

[a]Airfoil section	c_f/c	ϕ (deg)	$t_{0.9c}/c$	R_e	Turbulence factor	Reference
NACA 0009	0.30	11.6 to 42.8	0.022 to 0.033	2.8×10^6	1.93	1
NACA 0009	.20 .30 .40	11.6 to 40	.022 to .030 .022 to .036 .022 to .043	2.4 to 2.8	1.93	2
NACA 66(215)-014	.30	8.0 to 30.0	.028 to .045	2.4	1.93	3
NACA 66(215)-216, a = 0.6	.20 .15	4.0 to 21.2	.028 to .039 .030 to .036	3.8 to 9.0	Approaching 1.00	4
NACA 66(215)-216, a = 0.6	.20	9.3 to 33.5	.032 to .037	3.8 to 8.2	Approaching 1.00	5
NACA 66(215)-216, a = 0.6	.20	9.0 to 27.6	.032 to .039	3.8 to 9.5	Approaching 1.00	Unpublished
NACA 65_3-418	----	8.5 to 20.5	.027 to .038	.75	1.60	Unpublished

[a]Designations of low-drag airfoil sections have been changed to the form prescribed on page 21a of reference 7.

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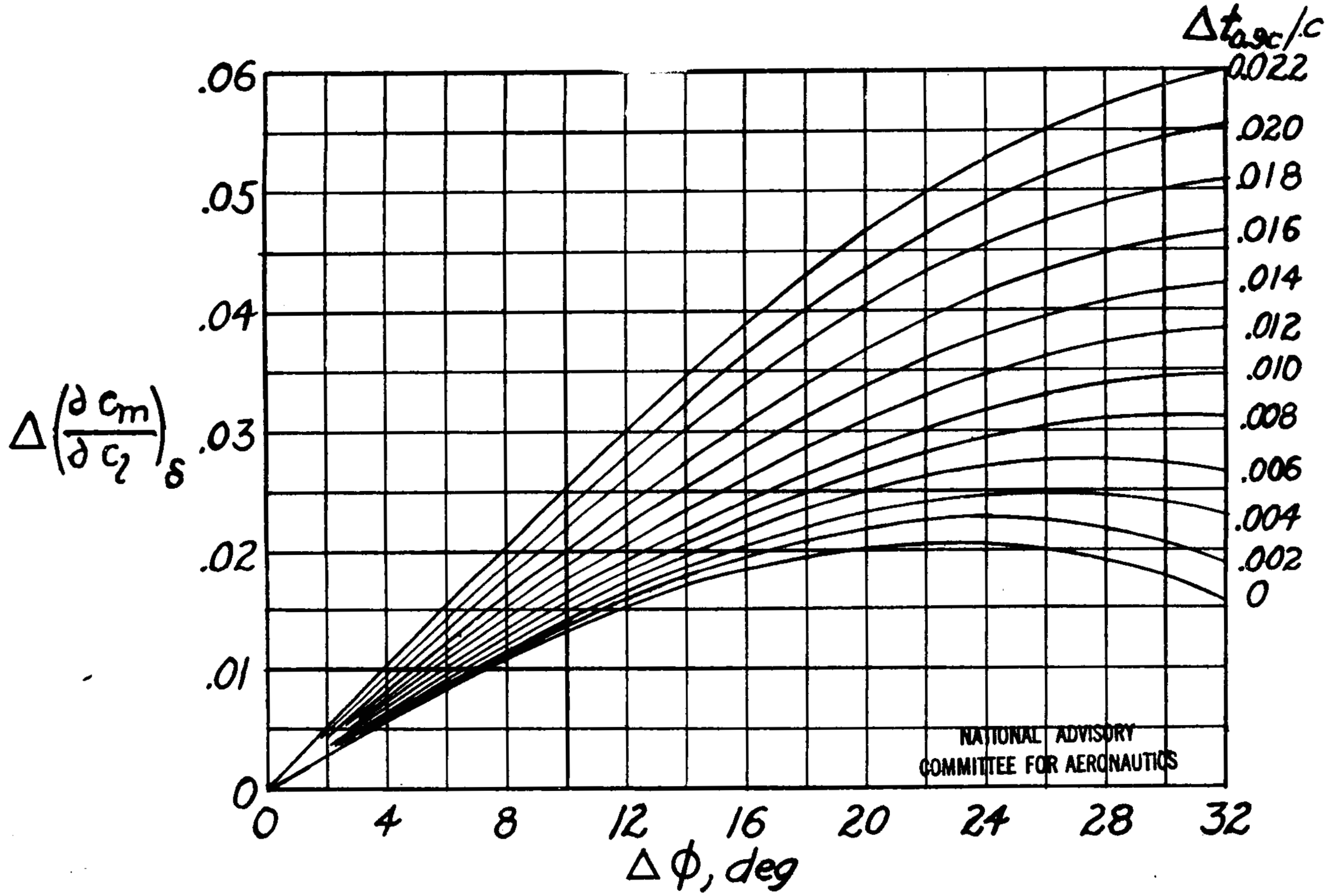

Figure 1.- Variation of increments of slope of pitching-moment curve $\left(\frac{\partial c_m}{\partial c_l}\right)_\delta$ with increments of trailing-edge angle ϕ and with increments of the airfoil thickness $t_{0.9c}$ at 0.9 chord. (Derived from data in references 1 to 5 and unpublished data.)

Airfoil	c_f/c	Reference	R_e	Leading edge
△ NACA 0009	0.30	1	3.8×10^6	Smooth
□ NACA 0009	.20	2	2.4	Smooth
◇ NACA 0009	.30	2	2.4	Smooth
▷ NACA 0009	.40	2	2.4	Smooth
○ NACA 66(215)-014	.30	3	2.8	Smooth
○ NACA 66(215)-014	.30	3	2.8	Rough
▽ NACA 66(215)-216, a = 0.6	.15	4	9.2	Smooth
△ NACA 66(215)-216, a = 0.6	.20	4	9.2	Smooth
◁ NACA 66(215)-216, a = 0.6	.20	5	9.2	Smooth
▽ NACA 66(215)-216, a = 0.6	.20	Unpublished	3.8	Smooth
▽ NACA 66(215)-216, a = 0.6	.20	Unpublished	8.5	Smooth
◿ NACA 65_3-418	---	Unpublished	.75	Smooth
◿ NACA 65_3-418	---	Unpublished	.75	Transition wire at 0.10c

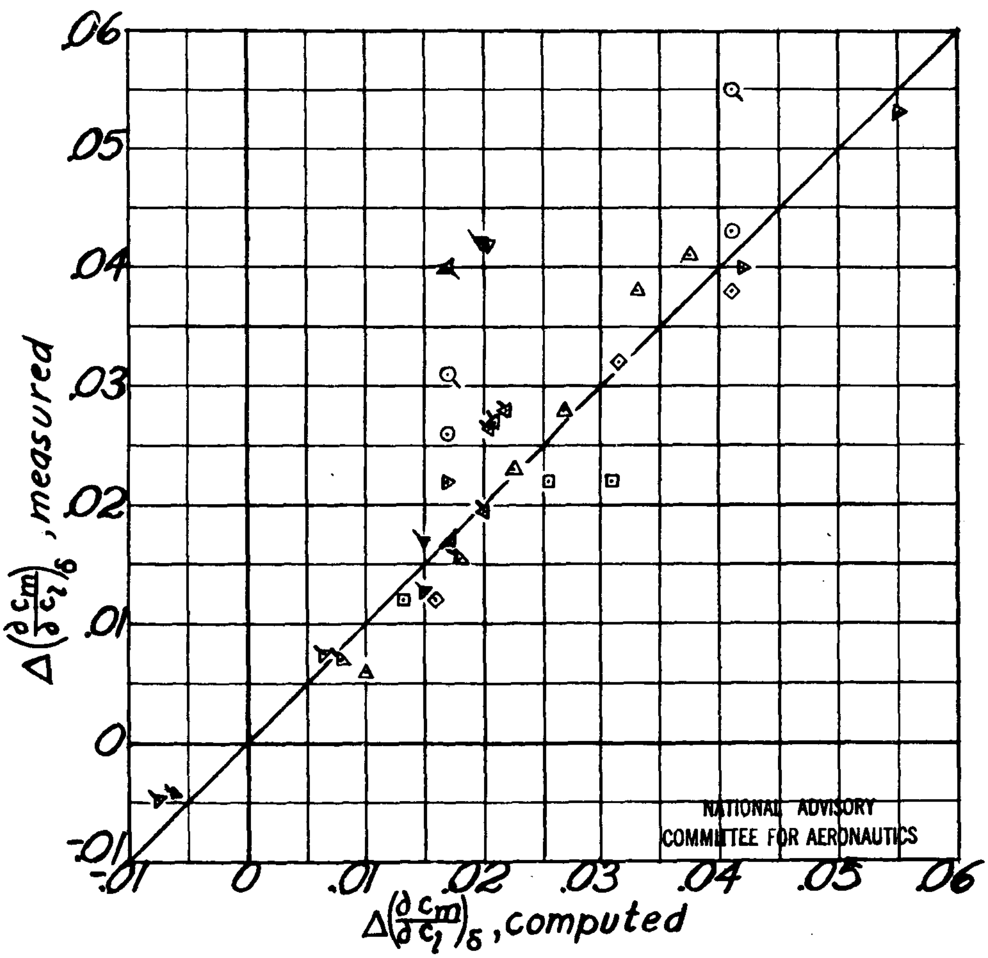

Figure 2.- Comparison of measured increments of slope of pitching-moment curve $\left(\frac{\partial c_m}{\partial c_l}\right)_\delta$ with increments computed from the design chart of figure 1.

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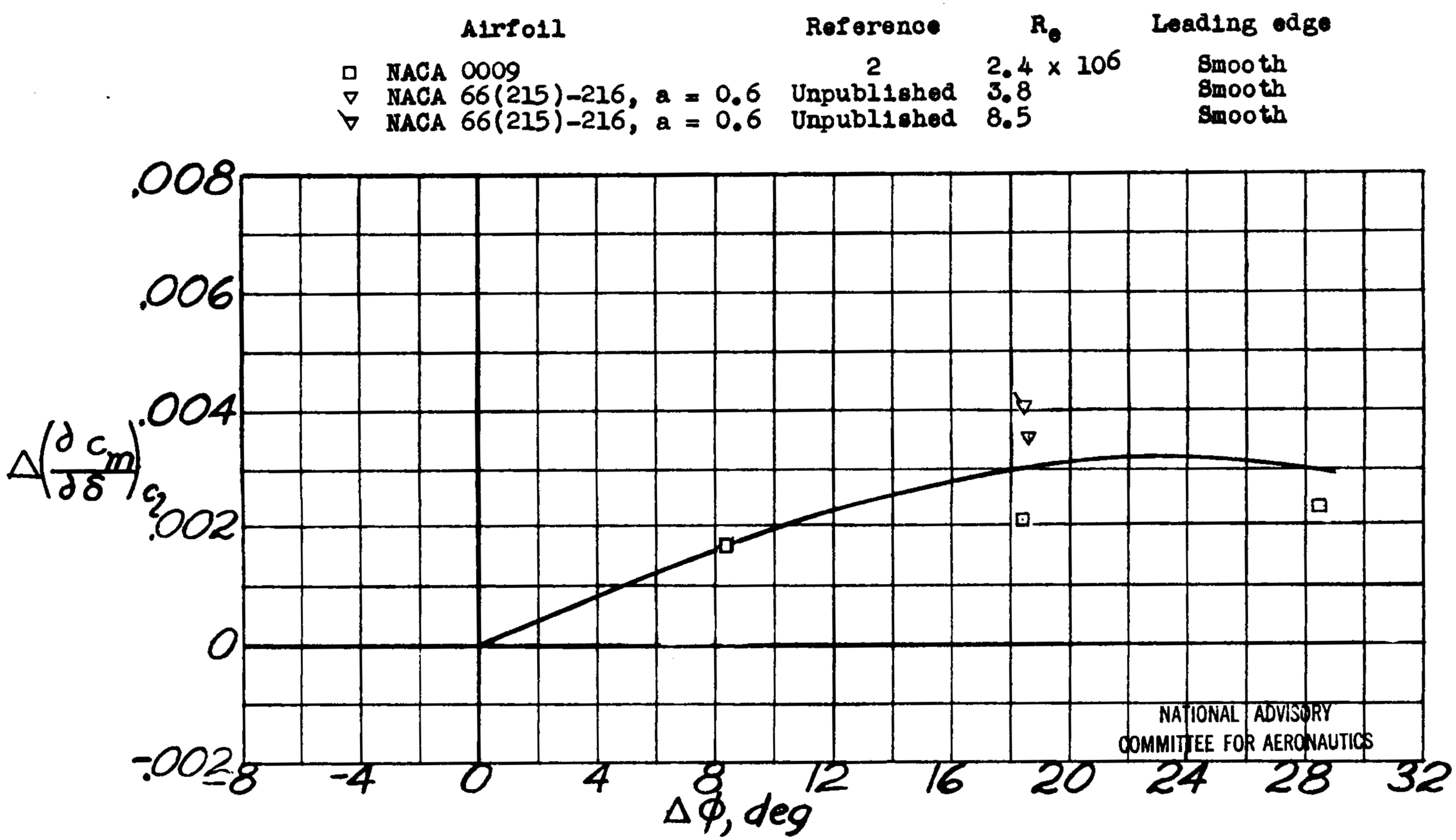

(a) $\frac{c_f}{c} = 0.20.$

Figure 3.- Variation of increments of slope of pitching-moment curve $\left(\frac{\partial c_m}{\partial \delta}\right)_{c_l}$ with increments of trailing-edge angle ϕ. Gap sealed.

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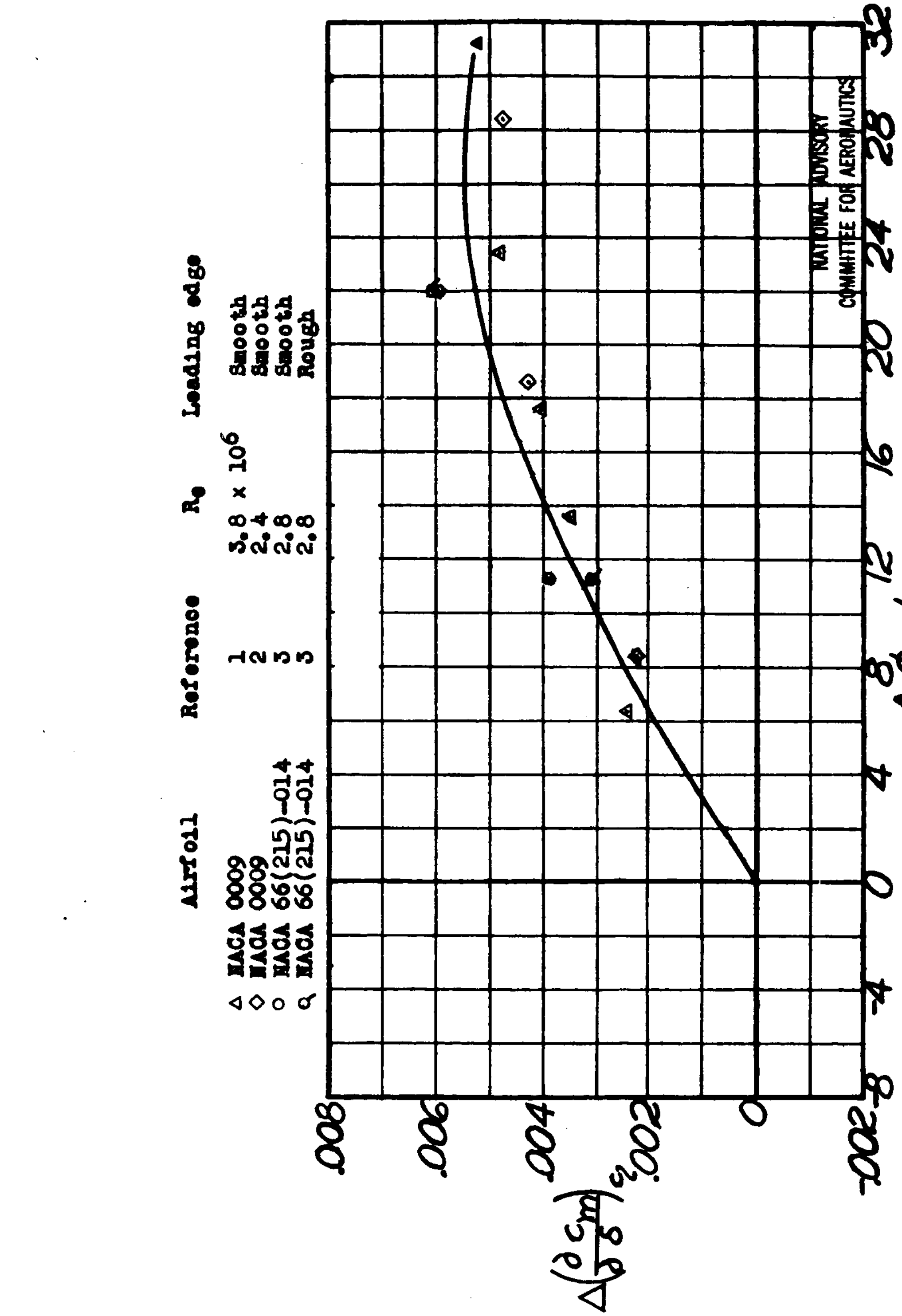

(b) $\frac{c_f}{c}$ = 0.30.

Figure 3.- Continued.

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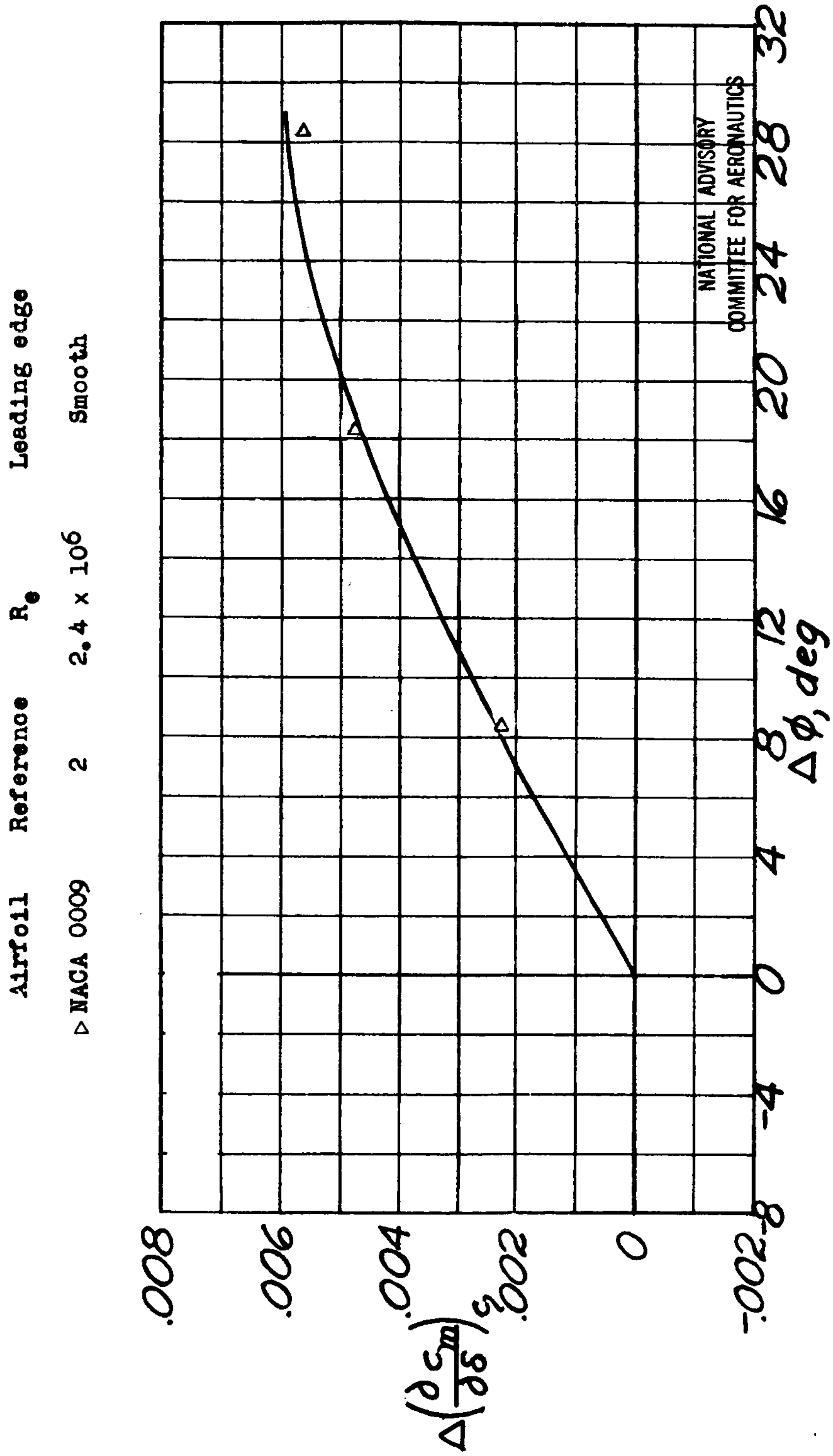

(c) $\frac{c_f}{c} = 0.40$.

Figure 3.- Concluded.

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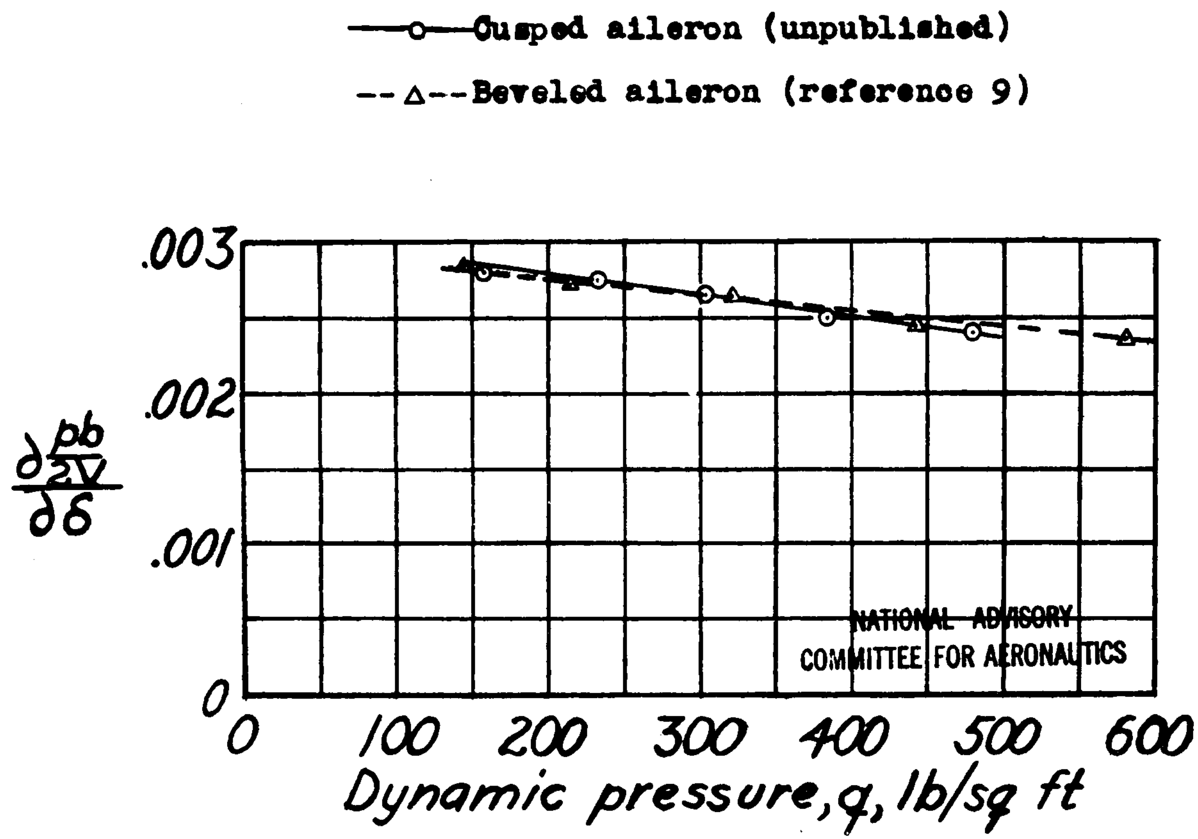

Figure 4.- Comparison of flight measurements of rolling effectiveness of cusped ailerons and beveled ailerons on a fighter airplane at high speed.